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MRI-to-PET 3D Image Synthesis

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Positron emission tomography (PET) provides in vivo molecular markers for diseases including Alzheimer's disease and is increasingly used in diagnostics, staging, and clinical trials. However, its adoption is limited by high costs, regulations, and radiotracer invasiveness. Multimodal biomarker frameworks like the amyloid/tau/neurodegeneration (A-T-N) system emphasize comprehensive assessment, but face these same barriers.

Medical image synthesis offers a solution by reconstructing unavailable modalities. Since PET's clinical value lies in regional uptake patterns rather than exact voxel intensities, perceptual loss functions that capture higher-level semantic features are essential for generative models. However, existing 2D, 3D, and 2.5D perceptual losses face challenges including limited volumetric context, scarcity of pretrained 3D models, and cross-plane optimization difficulties. We address tau PET synthesis from structural MRI by generating 3D pseudo-18F-flortaucipir standardized uptake value ratio (SUVR) maps from T1-weighted images. We propose a cyclic 2.5D perceptual loss that sequentially optimizes axial, coronal, and sagittal planes across training phases, enhancing volumetric consistency. Additionally, we standardize PET SUVRs by scanner manufacturer to reduce inter-manufacturer variability and preserve high-uptake regions. Our method is architecture-agnostic and achieves strong quantitative and qualitative performance across U-Net, UNETR, SwinUNETR, CycleGAN, and Pix2Pix. Notably, synthesized SUVRs show superior alignment with actual PET scans in brain regions critical to Alzheimer's tau pathology.

Keywords: *PET, MRI, Alzheimer's disease, 3D image translation, Perceptual loss*